In vitro cleaning potential of three implant debridement methods. Simulation of the non-surgical approach

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Abstract: OBJECTIVES To assess the cleaning potential of commonly used implant debridement methods, simulating non-surgical peri-implantitis therapy in vitro. MATERIALS AND METHODS One-hundred-and-eighty dental implants were ink-stained and mounted in combined soft and hard tissue models, representing peri-implantitis defects with angulations of 30, 60, and 90° covered by a custom-made artificial mucosa. Implants were treated by a dental school graduate and a board-certified periodontist for 120 s with following instruments: Gracey curette, ultrasonic scaler, and an air powder abrasive device with a nozzle for sub-mucosal use utilizing glycine powder. All procedures were repeated 10 times for each instrumentation and defect morphology respectively. Images of the implant surface were taken. Areas with color remnants were planimetrically determined and their cumulative surface area was calculated. Results were tested for statistical differences using two-way anova and Bonferroni correction. Micro-morphologic surface changes were analyzed on scanning electron microscope (SEM) images. RESULTS The areas of uncleaned surfaces (%, mean ± standard deviations) for curettes, ultrasonic tips, and air abrasion accounted for 74.70 ± 4.89%, 66.95 ± 8.69% and 33.87 ± 12.59% respectively. The air powder abrasive device showed significantly better results for all defect angulations ($P < 0.0001$). SEM evaluation displayed considerable surface alterations after instrumentation with Gracey curettes and ultrasonic devices, whereas glycine powder did not result in any surface alterations. CONCLUSION A complete surface cleaning could not be achieved regardless of the instrumentation method applied. The air powder abrasive device showed a superior cleaning potential for all defect angulations with better results at wide defects.

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In vitro cleaning potential of three implant debridement methods. Simulation of the non-surgical approach.

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Running title: Peri-implant cleaning assessment. Non-surgical approach.

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Abstract

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To assess the cleaning potential of commonly used implant debridement methods, simulating non-surgical peri-implantitis therapy in vitro.

Materials and Methods:

One-hundred-and-eighty dental implants were ink-stained and mounted in combined soft and hard tissue models, representing peri-implantitis defects with angulations of 30, 60 and 90° covered by a custom-made artificial mucosa. Implants were treated by a dental school graduate and a board-certified periodontist for 120 s with following instruments: Gracey curette, ultrasonic scaler and an air powder abrasive device with a nozzle for sub-mucosal use utilizing glycine powder. All procedures were repeated ten times for each instrumentation and defect morphology, respectively. Images of the implant surface were taken. Areas with color remnants were planimetrically determined and their cumulative surface area was calculated. Results were tested for statistical differences using two-way ANOVA and Bonferroni correction. Micro-morphologic surface changes were analyzed on scanning electron microscope (SEM) images.

Results:

The areas of uncleaned surfaces (%, mean ± standard deviations) for curettes, ultrasonic tips, and air abrasion accounted for 74.70±4.89%, 66.95±8.69% and 33.87±12.59%, respectively. The air powder abrasive device showed significantly better results for all defect angulations ($P < 0.0001$). SEM evaluation displayed considerable surface alterations after instrumentation with Gracey curettes and ultrasonic devices, whereas glycine powder did not result in any surface alterations.

Conclusion:

A complete surface cleaning could not be achieved regardless of the instrumentation method applied. The air powder abrasive device showed a superior cleaning potential for all defect angulations with better results at wide defects.

Introduction

The placement of dental implants to replace missing teeth has become a successful standard therapy with excellent long-term survival rates (Jung et al. 2012; Pjetursson et al. 2012). However, with a rising number of implants being placed, biological and technical complications will probably be more common in the future as well. Peri-implantitis already affects around 10% of implants and 20% of patients within 5 to 10 years after implant placement according to a recent review (Mombelli et al. 2012).

For the development of peri-implantitis, the formation of a biofilm on the implant surface plays the major etiological role (Pontoriero et al. 1994; Zitzmann et al. 2001). Hence, the treatment of peri-implant mucositis and peri-implantitis must include anti-infective measures (Heitz-Mayfield and Lang 2010). Currently there is no reliable evidence suggesting which could be the most effective intervention for non-surgical or surgical therapy of peri-implantitis lesions (Sahrmann et al. 2011; Esposito et al. 2012; Romanos and Weitz 2012) Non-surgical therapy was shown to be effective in the management of peri-implant mucositis, but treatment results are not predictable in the long-term (Renvert et al. 2008). The implementation of an initial non-surgical debridement phase as cause-related treatment, however, seems to be beneficial in terms of reduction of inflammation. This step can be performed either as an independent treatment in moderate cases or as a preconditioning of the soft tissues before surgical access follows at a later time point (Heitz-Mayfield and Mombelli 2014).

Various instruments have been proposed for implant surface debridement. The most commonly used instruments used for these purpose are curettes, ultrasonic devices and air-abrasives (Schwarz et al. 2005; Louropoulou et al. 2015). A recent *in vitro* study investigating implant debridement methods has shown that air-powder devices provide a superior cleaning potential when compared to curettes or ultrasonic scalers (Sahrmann et al. 2015). These procedures, however, were performed under conditions that have simulated an open flap surgery, i.e. without restrictions of working distance, instrument angulation and constricting soft tissues. The influence of inflamed peri-implant mucosa in terms of providing visual impairment and interference with implant surface accessibility was not yet investigated. Therefore, this *in vitro* study aimed to assess the cleaning potential of three different instrumentation methods commonly used for implant surface decontamination using a novel bone defect-model that includes a custom-made mucosa mask to simulate the conditions of non-surgical implant surface debridement. As secondary parameters, the influence of operator experience as well as morphologic implant surface changes were investigated. We

hypothesized that with regard to implant surface cleaning no differences between the utilized instruments are detectable when simulating the non-surgical approach.

Materials and Methods

Defect models

Polymethacrylate resin (Paladur clear®; Kulzer, Hanau, Germany) was used for the fabrication of custom-made standardized models with three different defect morphologies, i.e. opening angulations of 30°, 60°, and 90° (horizontal defect). These models simulated circumferential peri-implant defects with a height of 6 mm (Figure 1).

One-hundred-and-eighty implants (SPI Element RC Inicell®, Thommen Medical, Grenchen, Switzerland) with a length of 11 mm, an endosseous diameter of 4.2 mm and a mean roughness of the endosseous surface of 2.35±0.25 µm were coated with water-insoluble, non-covering ink (Staedler permanent Lumocolor, Nürnberg, Germany). This staining simulated an optically identifiable "biofilm" surrogate for the subsequent assessment but was covered during surface treatment as follows: Implants were inserted into the defect models in a way that the rough surfaces leveled with the upper edge of the resin model. Thereafter, a nontransparent custom-made well-fitting mucosa mask was imposed over the model. During gelatine preparation (gelatine ballistic type 1, Gelita, Eberbach, Germany), it was made opaque with milk powder (Rapidlait, Migros, Switzerland) to prevent visual control of the performed cleaning and it was additionally colored red with 3% strawberry red solution E124 (Werner Schweizer AG, Richterswil, Switzerland) to imitate a mucosal appearance. Both, implants and mucosa mask were only used once, i.e. a new implant and mask was prepared for every instrumentation.

Instrumentation

The sequence of instrumentation, i.e. the instrument as well as the type of defect was randomized before the beginning of the study according to a computer-generated randomization list (www.random.org). Three different instruments were used:

1) A Gracey steel curette Nr. 11/12 (Deppeler, Rolle, Switzerland)

2) An ultrasonic device with a steel tip (PiezoLED Scaler Tip 201, KaVo, Biberbach/Riss, Germany)

3) An air powder abrasive device (AIR-FLOW Master®; EMS, Nyon, Switzerland) with glycine powder (AIR-FLOW® powder perio; EMS, Nyon, Switzerland) and a nozzle for subgingival use. The instrumentation was performed at maximum settings for “lavage” and

"power". The nozzle was only used once for every implant and discarded afterwards. All instrumentations were performed by a dental school graduate (A. M.) and a board-certified periodontist (V.R.). The treatment time was restricted to 120 s per defect. After instrumentation, the mucosa mask and the implants were removed from the models.

Assessment of surface cleanliness

Loose color debris was removed from the implant surface with gentle air-water spray. Afterwards, digital photographs of the implant surface were taken with standardized parameters (camera: Canon EOS 500D; objective: Canon EF 100mm f/2.8 Macro USM; flash: Canon Macro Ring Lite MR-14EX; Tokyo, Japan; photos were taken in dark ambience). A blinded examiner, who was unaware of the performed treatment, defect type and operator, performed the evaluation regarding the cleanliness of the surfaces. Color remnants were then identified with a custom-made planimetrical software (PPK, Zurich, Switzerland) described elsewhere (Sahrmann et al. 2013), and the total residually stained surface was calculated (ImageJ 1.46r, National Institutes of Health, Bethesda, Maryland, USA).

Assessment of surface alterations

Scanning electron microscopy (Carl Zeiss Supra 50 VP FESEM, Carl Zeiss, Oberkochen, Germany) was performed on the instrumented surfaces in order to assess any modifications. Images were taken at 10 kV with a working distance of 9 mm and a magnification of 10.000x. The surface of an untreated implant served as control.

Statistics

Means and standard deviations of the percentages of uncleaned surface were calculated. Differences between different defect angulations, instruments, and operators were tested by parametric two-way ANOVA with Bonferroni correction. P-values < 0.05 were regarded as statistically significant for all performed tests.

Results

Uncleaned areas remained on all implant surfaces regardless of the instrument used, irrespective of defect angulation and operator experience. Powder abrasion, however, provided the most efficient stain removal, followed by ultrasonic instrumentation ($p>0.001$). The corresponding areas of uncleaned surfaces (%, mean ± standard deviations) for powder

abrasion, ultrasonic scalers and curettes were as follows: 33.87 ± 12.59%, 66.95 ± 8.69%, and 74.70 ± 4.89%. All these results were significantly different ($P < 0.0001$).

For both the powder abrasive device and the ultrasonic scaling the cleaning efficacy increased significantly for defects with larger angulations (see Table 1). Airflow showed better results for all defect angulations ($P < 0.0001$), providing the best results at the 90° (21.20 ± 8.96%), followed by the 60° defect angle (40.30 ± 7.12%). The worst result was for the 30° defect angulation with 40.15 ± 10.40%, which was still better than any of the other instruments and defects. For details see Figure 3 and Table 1.

With regard to operator experience, no significant differences were observed between the dental school graduate and the board-certified periodontist for the powder abrasive device and the ultrasonic scaler. Gracey curettes, however, presented the only exception, where significantly better results were found for the more experienced dentist (72.27 ± 5.06% versus 77.14 ± 3.54%, $P < 0.0001$; details are shown in Table 2).

SEM images displayed distinct surface alterations after instrumentation with curettes and ultrasonic tips on both the polished and the rough implant surface when compared to untreated control surfaces. These alterations could already be macroscopically identified and showed a nearly complete elimination of the original surface structure after instrumentation on the SEM images. In contrast, no such surface alterations were observed after air powder treatment (Figures 4a and 4b).

Interaction effects were detected for the curette in the 90° defect and the air powder in the 60° defect ($p<0.001$).

Discussion

The aim of this *in vitro* study was the investigation of the cleaning efficacy of three different instruments when simulating the non-surgical approach to implant surface debridement in vitro. Two main results were found: 1) Air powder abrasion provided clearly superior cleaning efficacy when compared to Gracey curettes and ultrasonic scalers, with best performance in horizontal defects. 2) Stained areas remained in all implant surfaces, irrespective of operator experience, cleaning method applied and defect angulation. Therefore, the hypothesis, that all instruments perform comparably, was rejected.

Currently available evidence does not allow any specific recommendations for non-surgical or surgical therapy of periimplantitis (Heitz-Mayfield and Mombelli 2014). It has been further stated, that the results of non-surgical treatment of peri-implant diseases are not predictable on

the longer terms (Renvert et al. 2008). The impossibility of achieving a satisfactory percentage of cleaned surfaces by non-surgical implant debridement, which was the main finding of the present investigation, could be one self-evident reason for this clinical fact.

The cleaning efficacy presented in this study was inferior as compared to earlier publications with a similar set-up, which showed that up to 95% of the implant surface was reached by an airflow device (Sahrmann et al. 2013; Sahrmann et al. 2015). This can be explained by three factors. Firstly, the cited studies imitated open access conditions, allowing for visual control and unrestricted access to the implant surface. Secondly, a different implant type with wider threads was used, which also favored a better surface accessibility. Last, these implants were placed deeper into the models, as they are designed as bone level implants. Therefore, access for instrumentation was even more difficult.

Operator experience had an impact only on the results after instrumentation with Gracey curettes. This finding is not surprising when relating it to the literature on operator's influence on scaling and root planing of periodontally involved teeth. With regard to this question, consistently better results are also found for more experienced operators when cleaning teeth during periodontitis treatment (Brayer et al. 1989; Fleischer et al. 1989; Kocher et al. 1997). However, due to threads and a micro-rough surface implants are assumedly even more difficult to clean than mostly convex root surfaces. Operator experience did not have any impact on the cleaning efficacy of air powder abrasives with a subgingival nozzle. Hereby, the mode of application might leave little room for variation and proved to be less technique sensitive than the demanding scaling technique with Gracey curettes.

Interaction effects of our data suggest a relatively worse cleaning potential for air powder in the 60° defect and for curettes in the 90° defect. As to the air powder, these effects were due to the outliers (Fig. 3). Though these effects were statistically detectable, a plausible conclusion for the clinical situation does not seem reasonable.

Another factor that was investigated was the change of implant morphology. Various publications have shown that Gracey steel curettes as well as ultrasonic scalers with universal tips leave pronounced traces on the implant surface (Fox et al. 1990; Mengel et al. 1998; Unursaikhan et al. 2012). In contrast, the application of glycine powder was not shown to result in specific alterations of SLA® titanium surfaces (Schwarz et al. 2009; Sahrmann et al. 2013; Sahrmann et al. 2015). A recent systematic review therefore proposed air abrasives as the instrumentation method of choice if surface integrity needs to be maintained (Louropoulou et al. 2012). The results of the present study confirm this suggestion. The investigated SEM images demonstrated significantly altered micromorphologies on the

polished as well as the rough titanium surfaces after instrumentation with both Gracey curettes and ultrasonic scalers, whereas the treatment with glycine powder did not lead to any micromorphological changes. The issue of surface alteration is of special interest in cases where the treatment plan involves later regenerative procedures. During the last decades, massive efforts have been made to optimize implant surface biocompatibility. Changing implant morphology by instrumentation may interfere with this important biologic property.

One limitation of this study was its *in vitro* design, testing only one implant type. In clinical practice, the individual implant type and its surface modification will influence biofilm formation as well as the ease of removal thereof. Furthermore, the design of a tapered suprastructure may further complicate adequate access to the affected surface. The employed model simulates the situation with a removable suprastructure held by screw-retention, as individual superstructure designs may show considerable variations. This type of defect model however as well as the use of indelible ink for biofilm imitation were already established in earlier studies, which investigated implant debridement under open access conditions (Sahrmann et al. 2013; Sahrmann et al. 2015). One might argue that the properties of indelible ink, which can be easily detected by direct assessment of photographs, do not completely match those of true biofilm. However, ink remnants have the advantage of being detected easily in a direct assessment by photographs, which renders the performed technique more robust against confounders than the area-specific assessment of biofilm that requires several analytical steps, each of it highly fault-prone (Ntrouka et al. 2011).

Since the employed set-up, however, is the same for all assessed instrumentation techniques, the results of this investigation do not become invalid by this limitation. The new set-up including the imposition of a mucosa mask was introduced to simulate clinical conditions typically found during non-surgical therapy. Furthermore, the present design involves deeper inserted hard tissue level implants instead of soft tissue level implants. The opaque gelatin mask, serving as imitation of edematous mucosa, remained in its original position during the duration of the instrumentation process, where it fulfilled its purpose of impeding visual control of the performed cleaning as well as limiting the access to the implant surface. Therefore, this model proved to be a valid standardized imitation of the inflamed clinical situation.

Conclusion

In this *in vitro* study simulating the non-surgical approach to implant debridement, a complete surface cleaning could not be performed regardless of the instrumentation method applied.

The use of an air abrasive device applying glycine powder with a subgingival nozzle provided clearly superior cleaning results when compared to Gracey curettes or ultrasonic scalers. This superiority was more pronounced in wide defects, irrespective of operator experience. No detectable surface alterations were generated by this treatment modality, whereas Gracey curettes and ultrasonic tips led to more pronounced changes of implant micromorphology.

Acknowledgement

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Conflict of interest

The authors declare no conflict of interest related to the present study. The implants used in the present study were kindly provided by Thommen Medical (Grenchen, Switzerland). EMS (Nyon, Switzerland) provided the AIR-FLOW® powder perio and the nozzles for subgingival use.

Tables

Table 1

Means ± standard deviations (%) and medians (interquartile ranges), the latter as second lines in rows, of residually stained surface areas after treatment with different instruments.

	30°	**60°**	**90°**
Gracey curette	76.50 ± 3.82 **A** 76.0 (6)	73.65 ± 5.34 **A** 73.0 (8)	73.95 ± 5.23 A 75.0 (9)
Ultrasonic	74.10 ± 8.99 **A** 72.5 (12)	66.25 ± 5.89 **AB** 65.0 (9)	60.45 ± 4.54 **B** 60.5 (8)
Air powder abrasion	40.15 ± 10.40 **C** 38.0 (15)	40.30 ± 7.12 **C** 38.5 (6)	21.20 ± 8.96 **D** 20.5 (14)

Each subgroup consisted of 20 implants (ten per operator) resulting in 180 implants treated.

Tests for statistically significant differences were performed using parametric two-way ANOVA with Bonferroni correction.

Different capitals indicate groups with statistical significant differences ($P < 0.001$).

Table 2

Results of the different operators

Means ± standard deviations (%) and medians of residually stained surface areas after treatment with different instrumentation techniques.

	Operator 1	**Operator 2**
Gracey curette	77.14 ± 3.54 **A** 77.32	72.27 ± 5.06 **B** 72.28
Ultrasound	68.71 ± 8.36 **C** 66.69	65.18 ± 8.79 **C** 63.25
Air powder abrasion	34.16 ± 13.79 **D** 36.45	33.57 ± 11.49 **D** 32.57

(operator 1- dental school graduate, operator 2 - board certified periodontist)

“Each subgroup consisted of 30 implants (ten per each defect and operator) resulting in 180 implants treated.“

Tests for statistically significant differences were performed using parametric two-way ANOVA with Bonferroni correction.

Different capitals indicate groups with statistical significant differences ($P < 0.001$).

Figures

Figure 1

Schematic illustration of the custom-made standardized models with three different defect morphologies, i.e. opening angulations of 30°, 60°, and 90°. The right image shows the custom-made mucosa mask, which was imposed over the respective models, serving as imitation of edematous mucosa.

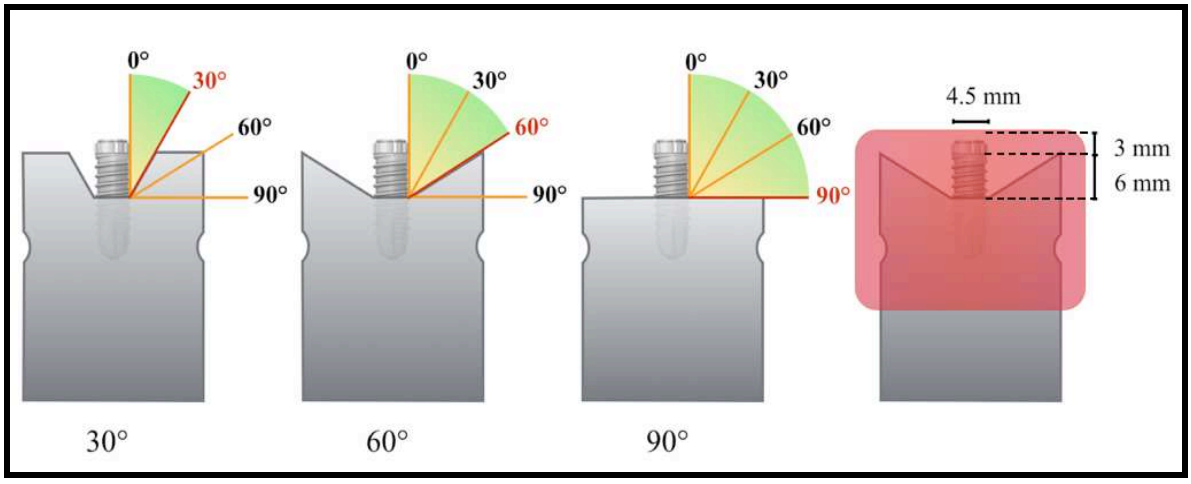


Figure 2

Treatment performed with Gracey curette (a), the ultrasonic scaler (b) and the powder abrasive device (c).

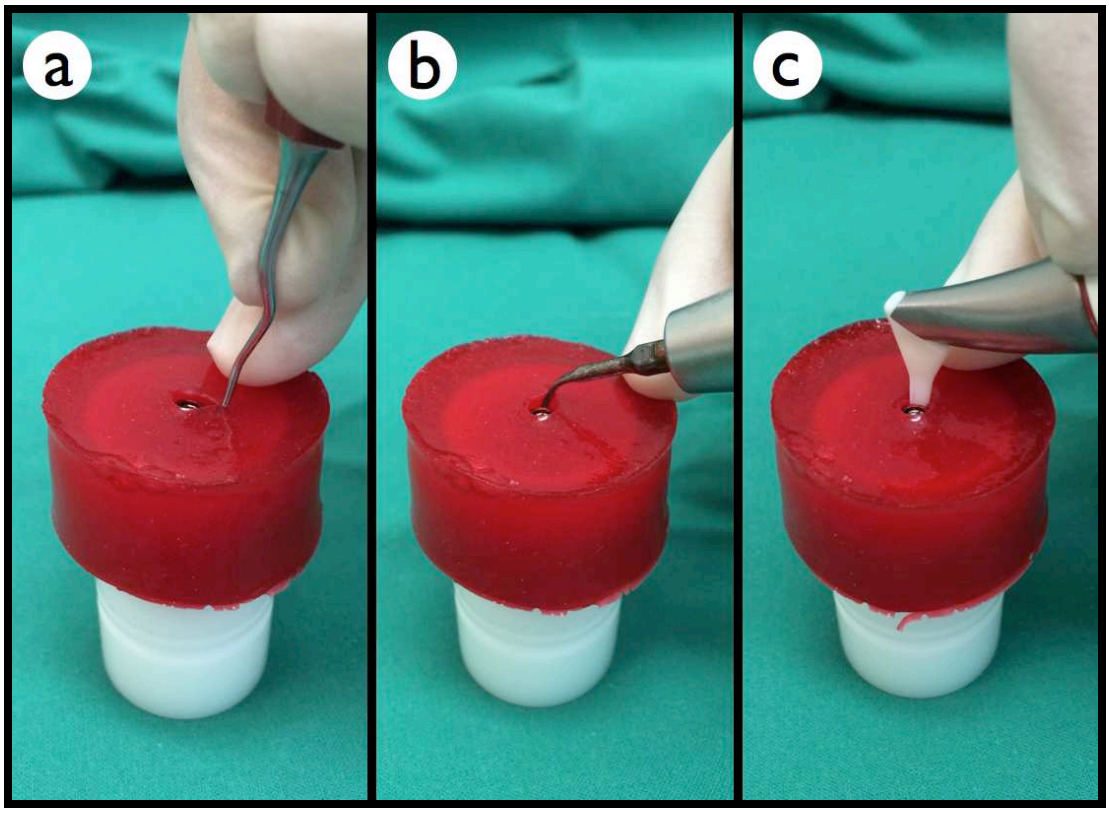
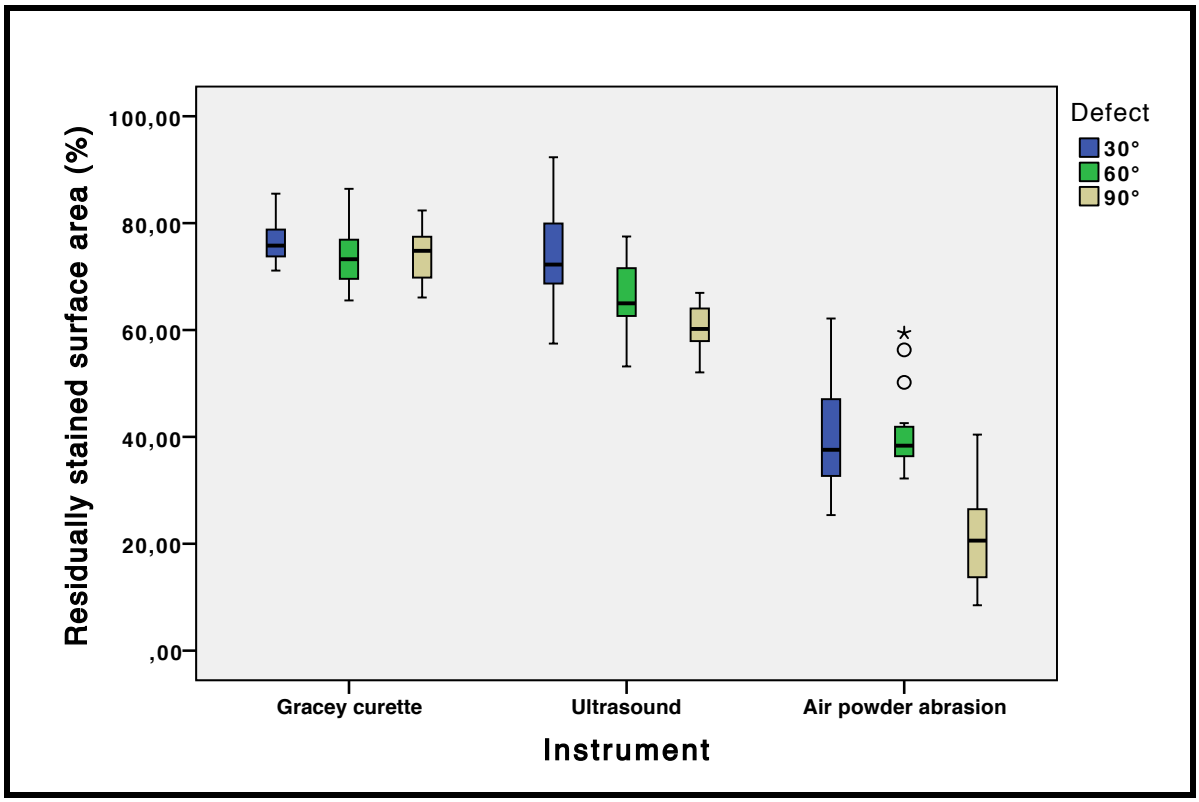


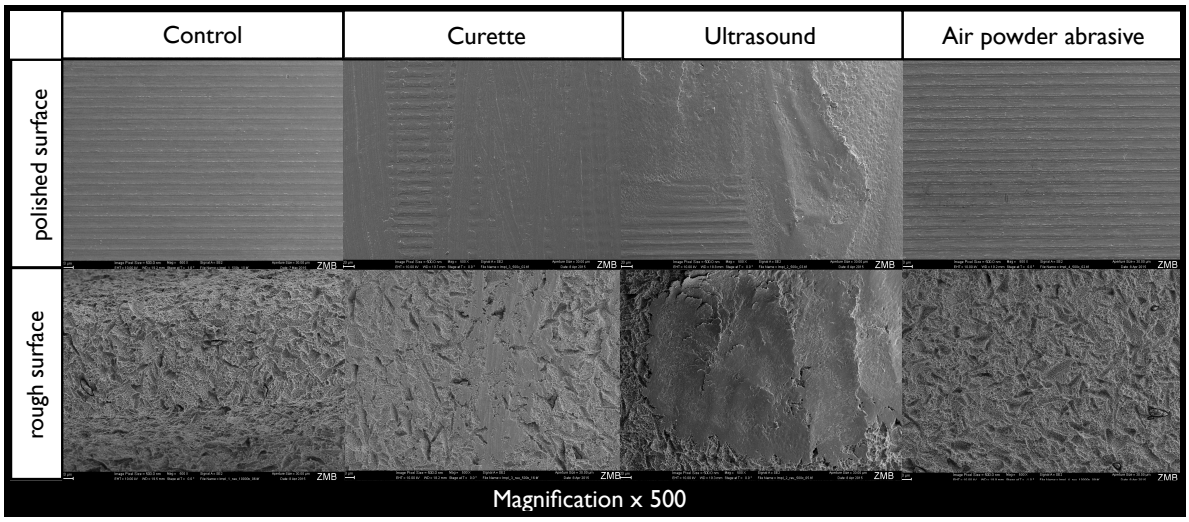
Figure 3

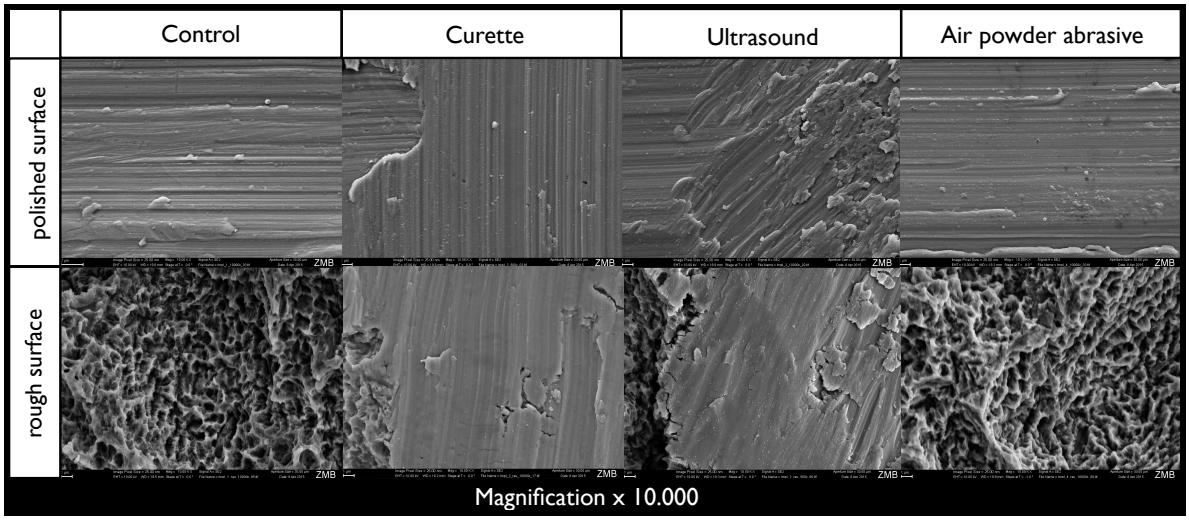
Boxplot presenting the residually stained surface areas (%) for the different instruments splitted by defect angulations.



Figures 4a and 4b

Scanning electron microscopy images of an untreated control and surfaces treated by the different instruments at a magnification of 500x (Figure 4a) and 10.000x (Figure 4b). Polished (upper row) and rough (lower row) surface areas of the implants are depicted.





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